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MARKET ANALYSIS OF SEISMIC SECURITY SYSTEMS

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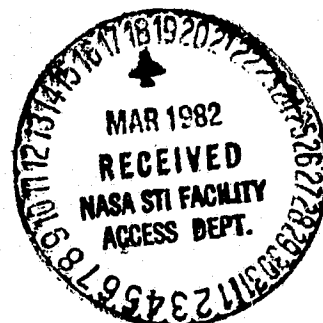
July 1981

Prepared for:

National Aeronautics and Space Administration
Technology Transfer Division
Code: ETT6
Washington, D.C. 20546

Attention: Ray L. Gilbert

Contract NAS2-10143



SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
Cable: SRI INTL MPK
TWX: 910-373-1246



SRI International



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Prepared by:

Steven Taglio
NASA Technology Applications Team

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SRI Project 8134

Approved by:

Robert S. Ratner, Executive Director
Systems Management Division

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I INTRODUCTION

The NASA Activity Monitor is a seismic security system that can discern activity at the sensor level. Unlike commercially available systems where sensing capabilities are limited to large zones, the NASA Activity Monitor allows discretionary coverage of a perimeter. A prototype, developed by engineers at NASA Ames Research Center (ARC), is based on seismic technology used in the Apollo Lunar Exploration Program. This prototype is scheduled to be installed around the maximum security cell block at the California State Prison at San Quentin for testing in late 1981. A patent has been applied for on the system, and a license to produce it commercially can be obtained from NASA.

Background

At the request of Warden George Sumner of the California State Prison at San Quentin and Mr. J. J. Enomoto, then Director of the California State Department of Corrections, representatives from ARC, NASA Headquarters, and the SRI Technology Applications Team (TATeam) met with members of the California State Department of Corrections in the fall of 1978 to identify the security needs of the state's correctional system. At that time correction officials expressed a need for a cost-effective method of detecting tunneling by inmates that is better than the current methods of tunnel detection, which include informants, labor-intensive searches, and accidental discovery. For example, one tunnel was discovered when it collapsed after a truck drove over it.

A survey of correction officials in California, Colorado, Florida, Iowa, Louisiana, Minnesota, New York, Texas, and Washington showed that other state correction departments were also interested in improved methods of tunnel detection. Specifications submitted by California authorities were for an inexpensive, reliable system that would not require additional or specially trained personnel. Ideally, they wanted a passive system that could detect slight ground movements below surface level, locate the area of activity, and operate accurately in varying weather conditions.

Objective and Method of Approach

The objective of this report is to provide information on the commercialization potential of the NASA Activity Monitor. Data on current commercially available products, market size, and growth are combined with information on the NASA technology and the projected impact of this technology on the market. To collect the data, we contacted manufacturers of similar products for product line specifications and market

information and to determine possible interest in the NASA technology. A market sector was identified through these contacts and verified through discussions with industry experts. Selected users within the sector were then polled to determine user need and the potential market size for the NASA Activity Monitor. This information was combined with the total number of potential users in the market sector to arrive at an estimate of market penetration.

II SEISMIC SECURITY SYSTEMS: AN OVERVIEW

Seismic security systems are composed of sensors and signal processors. Seismic vibrational sensors, or geophones, consist of a small solid rod of magnetized metal suspended on springs in a metal coil. As a seismic shock wave moves through the ground (similar to ripples on a pond) it creates minute vibrations. Geophones in the path of these shock waves are also vibrated, vibrating the magnetized rod, which creates a magnetic field and thus an electrical pulse. This pulse is transmitted via hardline cable to a signal processor. The largest supplier of geophones for seismic security systems is Geosource, Inc. of Houston, Texas.

The processor can be part of an above-ground console containing the alarm or it can be buried in the field. On receiving a signal, the processor amplifies it and then processes it. Each manufacturer's equipment uses different criteria for accepting a signal. Some processors rely on amplitude, screening out signals below a certain gain. Others require the pulse to be of a predetermined frequency--that is, rhythmic (for footsteps, for example) or consistent (for machinery, for example). Once a signal has been processed and has passed the screening criteria, it triggers an alarm, which can be an audible signal, flashing light, or a lit zone on a display panel.

Seismic Interference

A problem common among all seismic security systems is seismic interference, which decreases the sensitivity of the sensors and can allow undetected penetration of a monitored zone. Because of seismic interference, seismic sensors are not the most reliable equipment on which to base a security system.

Manufacturers have not yet learned how to totally eliminate this problem, as exemplified by the following caution in one company's product literature:

In all cases, lines of alarm and interference sensors should be located as far as possible from disturbance-generating areas and equipment such as air compressors, busy streets and freeways, railroads, etc.

Sensors should not be placed in areas where runoff water from drain spouts and drip lines, or fruit and nuts from trees, will fall in the immediate area of the sensor.

Methods of dealing with seismic interference vary and none seems to be totally successful.

Commercially Available Seismic Units

Seismic security equipment is commercially available from four identified sources: GTE Sylvania, Geotronics, Intrusion Detection Systems, and Sparton Southwest. These systems follow the basic pattern described above; variations occur in component design and pulse processing. Sensing is limited to zones that, for detecting human activity, range in length from a single sensor (12-ft radius) to 40 sensors (480 ft); the average length is 20 sensors (240 ft). Details on these four systems are discussed below and presented in Table 1.

GTE Sylvania, Inc. of Mountain View, California, manufactures the Seismic Processor System, SPS-1, which handles from 1 to 10 geophones per unit. When the signal enters the processor, which is buried on site, it encounters a gain that blocks out signals below a set amplitude. The closer the activity is to the processor, the stronger the shock wave and therefore the stronger the signal. The gain in the SPS-1 can be adjusted to accommodate variances in soil attenuations and the size of the area to be monitored. The denser the soil, the faster a shock wave will travel through it, and therefore the higher the gain. Similarly, the larger the area to be monitored, the lower the gain, allowing for the detection of activity farther from the sensor. Figure 1 shows GTE's specifications for the SPS-1.

Once a signal has cleared the gain, it triggers an alarm mode that sets off an on-site alarm. To avoid having an alarm go off on site, the SPS-1 can be hooked into a central monitoring unit located off site. Applications of GTE equipment include domestic and international manufacturers, military installations, and correctional facilities.

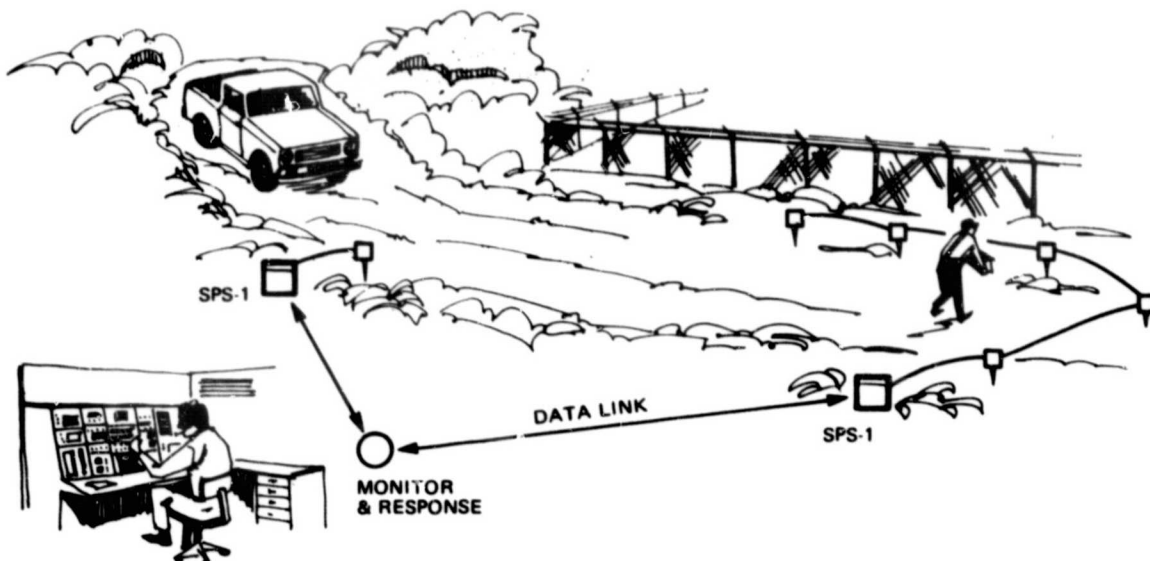
Geotronics, Inc. of Santa Clara, California, makes the GX series of seismic security systems. These systems are based on U.S. Patent 3,774,190 issued November 20, 1973. Monitoring units are of modular design and can handle from 1 to 4 zones. Each zone may be equipped with from 1 to 80 sensors. The suggested number of sensors is 40, spaced every 12 ft (see Figure 2). The signal processor, located at a central monitoring area, relies on frequency pattern detection to screen signals. The processor receives a pulse from the sensors and initiates a timer. Each subsequent pulse reinitiates the timing period until the

Table 1
COMPARISON OF COMMERCIALY AVAILABLE SEISMIC SECURITY SYSTEMS

System	Company	Number of Sensors Per Zone	Area Covered (ft)	Price* \$	Signal Processing	Applications
SPS-1	GTE Sylvania Security Products P. O. Box 188 Mountain View, CA 94042 (415) 966-2210	1-10	30 x 300	1,700	Adjustable gain, 5 increments 8 dB apart (74-106 dB)	Manufacturing facilities (domestic and international) Military Correctional facilities
GA-IRM	Geotronics P. O. Box 1221 Campbell, CA 95009 (408) 374-4974	1-80 (40 suggested)	12 x 480	892	Signal clears set gain and timer and counter. Three signals within time frame trigger alarm.	Home and estate owners (domestic and international) Vineyards State landmarks School facilities Storage/equipment yards
SSP-1	Intrusion Detection Systems, Inc. 2321 Verna Court Marina Business Park San Leandro, CA 94577 (415) 352-8820	1-40	12 x 240	850	Discriminator sensors block external signals, allowing only those emitted from monitored zone to trigger alarm.	Manufacturing facilities Distribution centers Prisons Warehouses Retail stores
Geophone Line Sensor (110-5124-001)	Sparton Southwest, Inc. P. O. Box 1784 Albuquerque, NM 37103 (505) 898-1150	10	33 x 330	1,350	Signal recognition allows only signal of a predetermined pattern to trigger alarm. Two models, pulsed and extended.	U.S.-Mexico border Alaska Pipeline

Note: Information supplied by manufacturers, their authorized dealers, and sales literature.

*Prices are for single-unit signal processors only and do not include geophones, installation charges, or bulk discounts.



Specifications

Typical Detection Range (radius)

Personnel:

10-35 ft.

Note: Detection range will vary
depending upon soil makeup

Vehicles:

100-300 ft.

Deployment

Hand emplaced

Internal Adjustments

Sensitivity (Gain)

Transducers (geophones)

1 — 10 geophones

Operating Temperature

Internal power: -20°C to $+70^{\circ}\text{C}$,
External power: -32°C to $+70^{\circ}\text{C}$

External Supply Voltage

8 to 16 V (12 V nominal)

Total Current Drain

6 ma (nominal)

Alarm Output

Relay contacts

Case Dimensions

9" x 8" x 4.5"

Weight

Approximately 7 pounds

Surge Protection

Surge arrestor on all lines used for
external connection

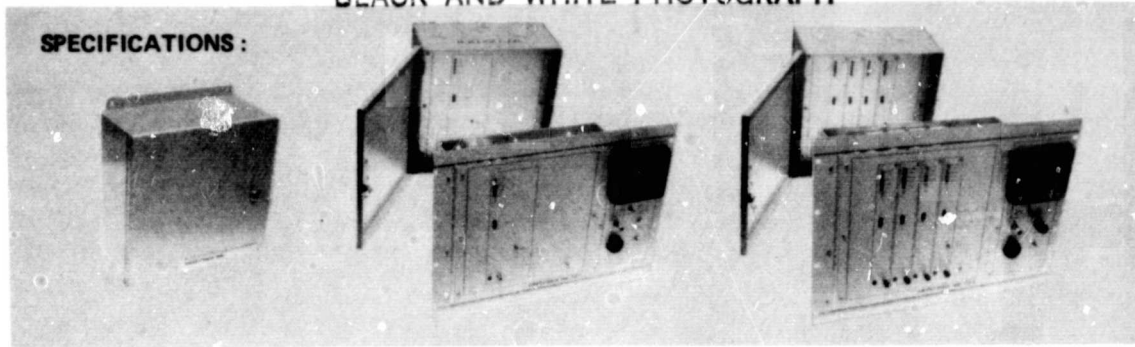
Connectors

Waterproof MS type

GTE

FIGURE 1 GTE SPECIFICATIONS FOR THE SPS-1

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SYSTEM TYPE	GX-P	GX-1	GX-1 RM	GX-4	GX-4 RM
ZONE CAPABILITY	PORTABLE	STANDARD	RACKMOUNT	STANDARD	RACKMOUNT
	1	1	1	4	4
PHYSICAL CHARACTERISTICS					
CABINET	STEEL HINGED COVER WEATHER PROOF KEY LOCKED HINGED PANEL	STEEL HINGED COVER DUSTPROOF KEY LOCKED HINGED PANEL	ALUMINUM HINGED PANEL	STEEL HINGED COVER DUSTPROOF KEY LOCKED HINGED PANEL	ALUMINUM HINGED PANEL
DIMENSIONS — (in.)	12.25 x 13.5 x 6.25	12.25 x 12.25 x 6.25	19.00 x 14.00 x 3.5	12.25 x 12.25 x 6.25	19.00 x 14.00 x 3.5
— (cm.)	31.12 x 34.29 x 15.86	31.12 x 31.12 x 15.86	48.26 x 35.56 x 8.89	31.12 x 31.12 x 15.86	48.26 x 35.56 x 8.89
WEIGHT — (lbs)	20	14	7	16	8
— (kilo)	44.0	30.8	15.4	35.2	17.6
OPERATING CHARACTERISTICS INPUT					
SENSOR TYPE	DIGITAL GRADE GEOPHONE				
NUMBER OF ALARM SENSORS (per line)	1 TO 40 } FORTY SENSORS PER LINE IS RECOMMENDED FOR EFFICIENT SENSITIVITY ADJUSTMENT.				
NUMBER OF INTERFERENCE SENSORS (per line)	1 TO 40 } EIGHTY SENSORS CAN BE EFFECTIVE WHEN INSTALLED IN MATERIAL OF SIMILAR DENSITY.				
FREQUENCY RANGE	8 - 14 Hz				
DETECTION RANGE — (feet)	0 - 20 RADIUS } AVERAGE SENSOR SPACING: ALARM 12 FEET (3.66 METERS) INTERFERENCE SENSORS 30 FEET (9.14 METERS)				
— (meters)	0 - 6.1 RADIUS				
SENSITIVITY ADJUSTMENTS	INDIVIDUAL ALARM/INTERFERENCE LINE(S) PLUS OVERALL SYSTEM ADJUSTMENT				
POWER REQUIREMENTS	12 VDC NOMINAL				
STAND BY POWER	SINGLE 12 V, 1.5 AMP RECHARGEABLE * BATTERY				
CURRENT REQUIREMENTS (per zone)	15.5 MILLIAMPS				
STANDARD (less options)	7.5 MILLIAMPS				
OPTIONS (additional)	28.0 MILLIAMPS				
GX-03 ENTER/EXIT TIME DELAY	300.0 MILLIAMPS				
GX-04 AUDIO MONITOR — (no load)	PLUG-IN CIRCUIT MAINTAINS FULL BATTERY POWER FROM A 12 VAC, 20 VA CLASS II * TRANSFORMER				
— (full load)					
CHARGING CIRCUIT					
OUTPUTS					
ALARM	LATCHING OPDT (2 FORM-C) RELAY 5 AMP CONTACT RATING				
PANEL INDICATORS (LED)					
SYSTEM TEST	RED				
ALARM SENSOR LINE	RED				
INTERFERENCE SENSOR LINE	RED				
ALARM CONDITION	RED				
ALERT	YELLOW - CONTINUOUS ACTIVATION ON INTERFERENCE LINE				
SAFE	GREEN				
ENVIRONMENTAL					
OPERATING TEMPERATURE	-10°C to +60°C				
STORAGE TEMPERATURE	-20°C to +70°C				
* BATTERY AND TRANSFORMER NOT PROVIDED					



FIGURE 2 GEOTRONIX SPECIFICATIONS FOR THE GX SERIES OF SEISMIC SECURITY SYSTEMS

full timing period has elapsed without the receipt of a subsequent pulse. A counter counts the number of such events; if a predetermined count is achieved before an output is supplied by the timer, an alarm goes off. Current applications of the GX series include home and estate owners, vineyards, state landmarks, school facilities, and storage and equipment yards.

Intrusion Detection Systems, Inc. (IDS) of San Leandro, California, manufactures and markets the SSP series of seismic security systems. The SSP can handle up to 4 zones of 20 sensors spaced every 12 ft (the manufacturer's suggested zone size and sensor spacing; see Figure 3). Approximately 35 ft beyond this perimeter ring of sensors, IDS installs a second ring of sensors called discriminator sensors. These sensors are used to block seismic interference (e.g., ambient noise and vibrations) from beyond the monitored zone. A shock wave from beyond the monitored area will hit the ring of discriminator sensors first. These sensors will then send a signal back to the monitor, blocking the subsequent signal from the perimeter signals. At some point after the intruder has entered the zone between the discriminator and perimeter sensor rings, the latter will detect the shock wave first. When this happens in amplitude strong enough to clear the set gain, the alarm will be triggered.

Current applications of the SSP-1 system include warehouses, manufacturing facilities, distribution centers, prisons, and retail stores. SSP system customer's include the Japanese Tea Gardens in San Francisco, California, Paul Masson Winery in Saratoga, California, and Pacific Telephone and Telegraph Company in Pleasant Hill, California.

Sparton Southwest, Inc. of Albuquerque, New Mexico, manufactures and sells a Geophone Line Sensor (part number 110-5124-001). The Sparton unit has a canister-type signal processor that is buried on site and can be connected to a central monitoring station via hardline cable or radio frequency data link. Battery operated, the Geophone Line Sensor is designed for low maintenance and remote use. Seismic signals are processed through two modes of operation: the detect mode and the classified mode. The detect mode allows any seismic activity to trigger the alarm; no screening takes place. The classified mode allows a signal through only if it fits one of two patterns: pulsed or extended. The pulse pattern, used for human detection, requires three seismic shocks of similar strength (strong enough to clear the gain). The third shock triggers the alarm mode. The extended pattern is used for vehicle detection. A continuous signal, with enough amplitude to clear the gain, triggers the alarm. In the classified mode, all signals not fitting one of these two patterns are ignored. Figure 4 shows Sparton's specifications for the Geophone Line Sensor and a flow diagram of a signal as it passes through the system.

One of Sparton's main customers is the U.S. Department of Customs, Bureau of Naturalization and Immigration, which uses the Geophone Line Sensor for border patrol. The unit is also used on the Alaska Pipeline.

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OPERATION

The Seismic Intrusion Detection System is an advanced buried seismic system which has been in the field for over nine years. It is used for outdoor perimeter protection or for indoor applications. The system employs all-weather, prefabricated sensors that capture intruders within their radius. The sensors transmit, when activated, specific seismic signals to the Signal Processor. An alarm condition results when an intruder enters within the omnidirectional detection range of the seismic sensor. Discriminator sensors are used to screen or cancel out unwanted freeway, train, machinery, or other ambient noise and vibrations.

HIGH RELIABILITY

Sensors can be installed in dirt, concrete, asphalt, walls, or atop buildings, on beams, in ceilings, and under structural members, without detracting from their ability to detect and alarm. All weather, multi-environment, solid state modular system is capable of differentiating between an intruder and natural disturbances such as auto traffic, trains, aircraft, earthquakes and sonic booms, thereby preventing false alarms. The sensors are buried and therefore are invisible to anyone.

SYSTEM LAYOUT

The array sensors may be placed to detect an intruder in one or a combination of patterns, the sensors may be aligned in a single or double string for PERIMETER protection, or in a cluster for either CORRIDOR or AREA protection. No line of sight is required. Excellent zoning for quick identification of intruder. Each sensor has a radius of effective sensitivity up to 10 feet. The coverage of the sensors will depend largely upon the relative quietness of the location. In remote areas the sensitivity can be greater than in urban environments. Sensor spacing of 12 feet is recommended.

AUDIO SYSTEM-MODEL (AUD-01): The Audio System picks up and amplifies the signals generated by the sensors. Footsteps, fence climbing or cutting become easily distinguishable audible sounds. When an alarm is triggered, the monitor, guard, or central station can touch a switch and listen to the footsteps of the intruder. He can note the number of intruders involved or if large animals are the cause.

OUTPUT: 2 Watts.

SIZE: 6" x 8" x 10"

CURRENT REQUIREMENT: 7 ma. at 27 volts dc.



*U.S. PATENT APPLIED FOR

SIGNAL PROCESSOR-GENERAL: The SSP-1 can be installed at any distance from the sensors. The cabinet is 16 gauge steel and the interior is water and dust resistant. Will handle up to 20 sensors on a single line. 40 sensors maximum per zone.

SIZE: 12" x 14" x 4". Shipping weight, approx. 8 pounds.

POWER REQUIREMENTS: 115 volts AC 50-65 Hz.

STANDBY POWER: Two 12-volt, 1.5 AH rechargeable batteries (Globe GC-1215 or equiv.)

OUTPUT RELAY: DPDT (2-form C). Contact rating 5 A resistive.

INPUT: A. ARRAY line will accommodate up to 20 sensors directly.

B. DISCRIMINATOR will handle up to 20 sensors directly.

OPERATING TEMPERATURE RANGE: 10°F. to 140°F. (excluding battery).

MODEL PWS-02 REGULATED POWER SUPPLY

INPUT: 115 volts. 50-65 HZ.

SIZE: 7-1/2" x 3"

OUTPUT: 1. +13.8 vdc at 800 ma. (battery float charge).

2. -13.5 vdc at 800 ma.

3. +9 volts at 200 ma. $\pm 5\%$.

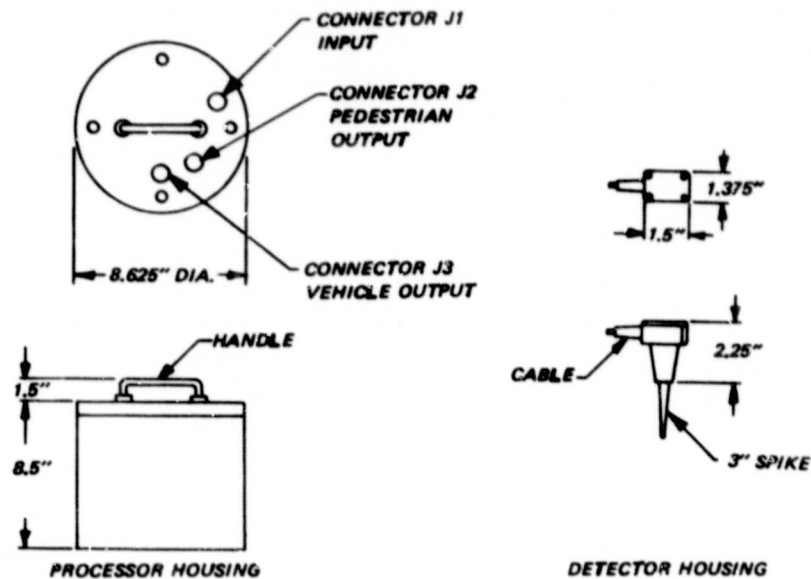
4. -9 volts dc at 200 ma. $\pm 5\%$.



INTRUSION DETECTION SYSTEMS, INC.

FIGURE 3 INTRUSION DETECTION SYSTEMS SPECIFICATIONS FOR THE SSP-1 SEISMIC SECURITY SYSTEM

GEOPHONE LINE SENSOR



CHARACTERISTICS

Size	Standard miniature geophone Processor (cylinder) 8.625-inch diameter × 8.5-inch length
Power Source	Commercial 6-V batteries
Probability of Detection and Correct Classification	95% minimum
False Alarm Rate	Less than one per day
Operating Life	One year (continuous duty, battery-limited)
Operating Temperature	-30°C to +60°C
Shock and Vibration	EIA Standard RS-316-A



FIGURE 4 SPARTON ELECTRONICS SPECIFICATIONS FOR THE GEOPHONE LINE SENSOR

III NASA ACTIVITY MONITOR

In the NASA Activity Monitor (Figure 5), 20 seismic sensors are spaced 23 ft apart along a perimeter (covering an area 460 ft x 23 ft). Figure 6 is a circuit diagram of the NASA Activity Monitor.

Modes of Operation

Outputs of individual sensors are fed to the Activity Monitor where they are processed in three modes of operation: (1) the summing mode; (2) the automatic scan mode; and (3) the manual up-down scan mode.

Referring to Figure 6, when the system is operating in the summing mode (ALL), the output of each sensor (11) passes through the corresponding electrical gate (17) and is summed in a receiver (18). The summed seismic signals are then amplified and detected in the receiver, whose output consists of signals in the band pass of 10-500 Hz. This output is fed into an audio detector (19), where it is compared against a certain seismic noise threshold level (trigger). If the received signal exceeds a certain threshold level, an output is fed to an audio oscillator (21), which then generates an audible tone or alarm and feeds it to a speaker (22) to sound an alarm.

A second output of the receiver (18) is fed to an automatic gain control detector (23) to produce an output that is fed to a switch (24). In one switch position, the output of the automatic gain control detector is fed to an automatic gain control circuit (25) to generate a DC output for controlling the gain of the receiver. The gain is controlled to a level slightly less sensitive than the background seismic noise level along the perimeter being monitored. Thus, the audio detector detects only those seismic signals exceeding the background noise level and produces an alarm via the audio oscillator and speaker. In the other switch position (24), the automatic gain control circuit is disabled, and a manual gain control circuit (26) enables an operator to adjust the gain of the receiver to a desired level.

In the automatic scan mode of operation, the ALL or SCAN switch (20) is switched to the SCAN position to enable a scanner (27) to sequentially multiplex the output of the individual sensors into the input of the receiver. The scanner includes an up-down counter run by a clock such that the various gates are sequentially opened for repetitive scanning through the individual sensors. As in the ALL mode, if the output signal of any one of the sensors exceeds a certain predetermined seismic noise threshold level, the output of the audio detector (19) initiates an audible alarm via the audio oscillator and speaker.

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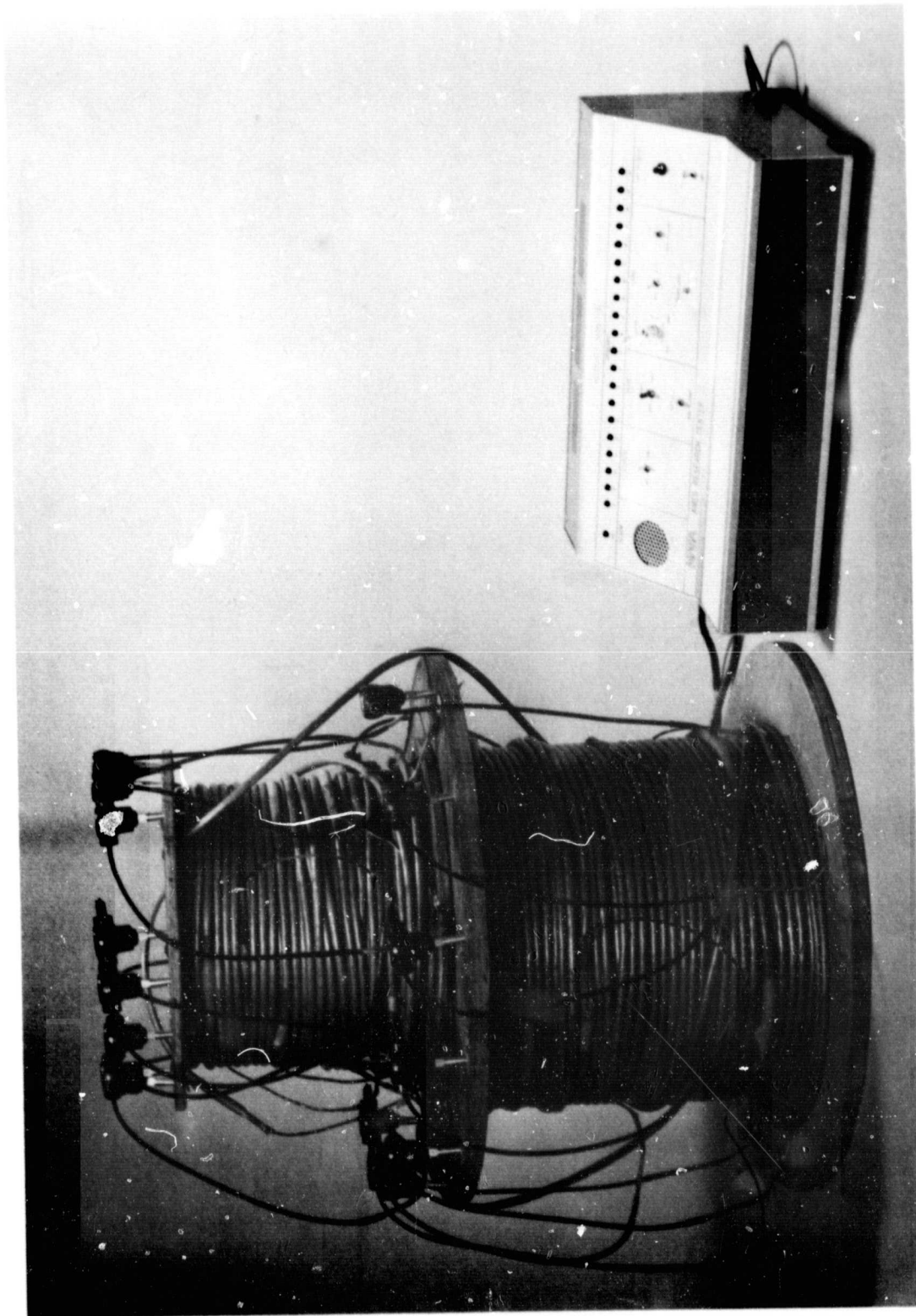


FIGURE 5 NASA ACTIVITY MONITOR WITH GEOPHONES AND WIRE

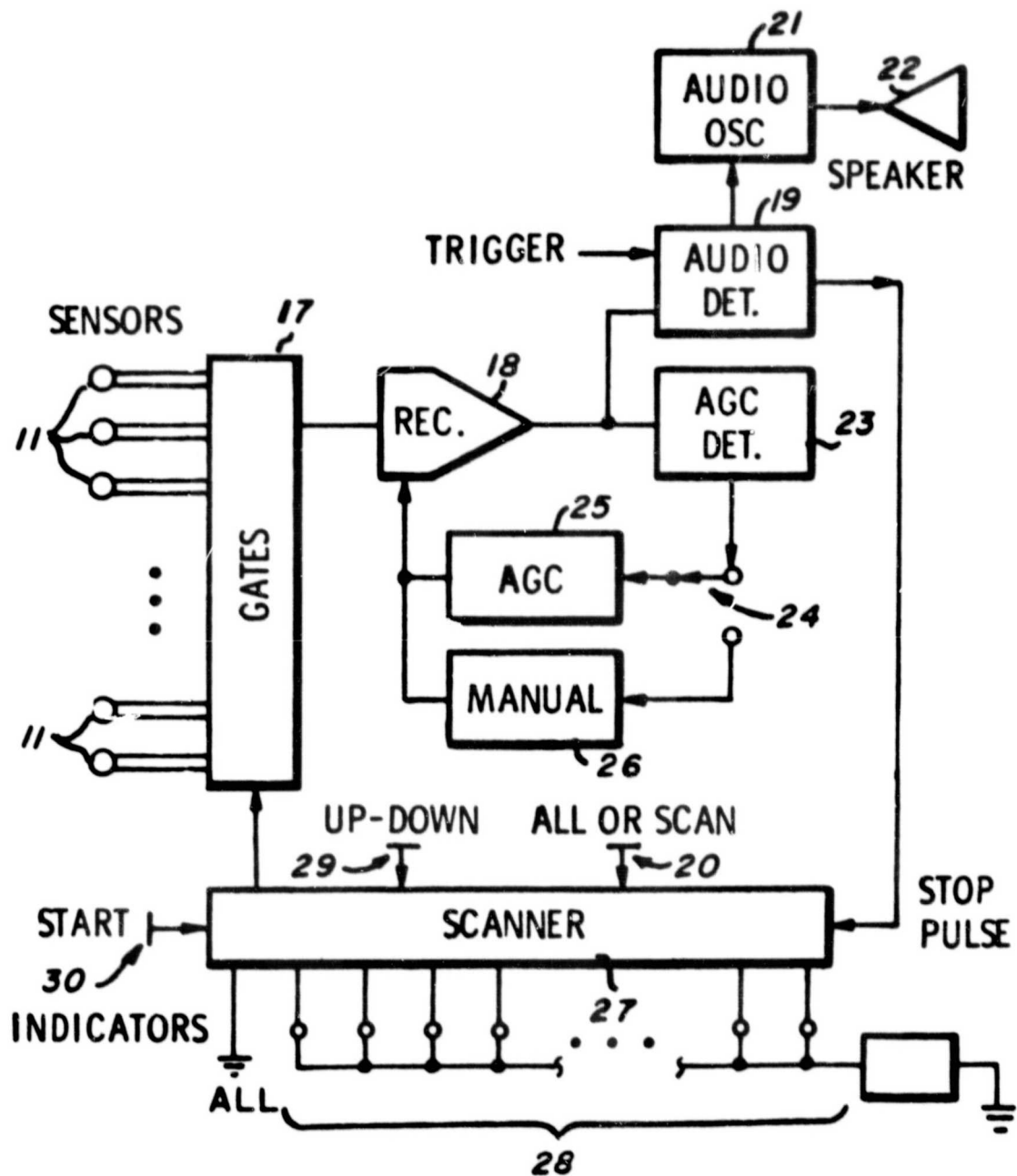


FIGURE 6 CIRCUIT DIAGRAM OF THE NASA ACTIVITY MONITOR

The audio detector also produces a stop pulse, which is fed to the scanner to stop the scanning action at the sensor having the output exceeding the predetermined seismic noise threshold level. A second output of the scanner is fed to an array of light-emitting-diode (LED) indicators (28), one for each seismic sensor. Thus, as the scanner multiplexes the output of the various sensors into the receiver, the respective LED indicators will sequentially light to show the particular sensor being interrogated at any given time. When the output of any one sensor exceeds the predetermined seismic noise threshold level, the scanner stops and the operator, by operating an up-down switch (29), causes the scanner to advance or back up for monitoring the individual sensors in the vicinity of the sensor that first indicated a signal exceeding the predetermined threshold level.

The manual up-down scan mode of operation causes the scanner to advance or back up by one sensor for each actuation of the manual up-down switch (29). The operator, by monitoring the relative signal levels at the sensors in the vicinity of the sensor that picked up the vibrations first, can determine the precise location of an intrusion. To restart the automatic scanning action, the operator presses a START switch (30), which reenables the automatic action of the scanner. A more detailed description and circuit diagrams of the NASA Activity Monitor can be found in the patent disclosure (Appendix A).

Estimated Production Costs

Table 2 shows the estimated production costs for the NASA Activity Monitor. The costs of parts are taken from the most current available electronic parts distributors' catalogues and reflect single-unit purchasing. Wherever a part was listed by manufacture and part number in the patent disclosure, that part was figured into the costing, even though a less expensive part with similar capabilities was available.

The calculations for labor are based on assembly personnel skill level of engineer technician. Salary is estimated from "Salaries of Scientists, Engineers and Technicians." Assembly time was derived from discussions with electronics assembly experts who reviewed the NASA Activity Monitor circuit diagrams. Assumptions include machine soldering and manual part stuffing and lead trimming.

Table 2

NASA ACTIVITY MONITOR: PRODUCTION COSTS

Parts

Gates (20)	\$ 16.80
Receiver	4.60
Audio oscillator	19.28
Audio detector	15.40
Automatic gain control detector	6.50
Automatic gain control	10.90
Manual gain control	2.50
Scanner	76.57
Console	<u>54.20</u>

Subtotal parts \$206.75

Labor

5.5 hr @ \$8.30/hr \$ 45.65

Subtotal direct inputs \$252.40

Overhead factor 100%* 252.40

Wholesale markup 50%* 252.40

Retail markup 50%* 378.60

Total \$1,135.80

*Standard overhead and wholesale/retail markup percentages.

IV SEISMIC SECURITY SYSTEM MARKET

Security equipment sales have grown steadily for the last 10 years. Because of increasing crime rates, it is predicted that 1982 sales of intrusion detection alarms will increase to \$445,640,000, up 45.1% from 1980 sales.* Because this figure includes all types and applications of intrusion detection equipment, it cannot be used for accurate projections of growth in seismic systems sales. One can assume, however, that seismic intrusion detection systems will benefit from the upward trend in security systems sales.

Currently, seismic security devices have found their greatest acceptance in storage and manufacturing facilities, prisons, and other sites where activity is limited for established periods. Because of their relatively low cost, seismic security systems are often used in conjunction with other security equipment, such as closed circuit television, and security guards. A common application of seismic security equipment is around minimum security sections of prisons. These systems help guard against the smuggling of contraband, such as alcohol and drugs, into prison facilities.

The ability of the NASA Activity Monitor to detect intrusion every 23 ft is not a selling feature in the established seismic security system market. According to sales representatives, potential customers seldom ask whether each sensor can be monitored individually, and the absence of this feature has never prevented a sale. The larger zone-sensing capabilities that current systems offer therefore seem to be more in tune with actual demand. These seismic systems are used primarily to detect entry, not point of entry. In addition, intruders moving quickly above ground can cross the frontage zone before the NASA Activity Monitor has a chance to distinguish the active sensor. For these reasons, it is not believed that the NASA monitor, in its current form, would appeal to the general seismic security system market.

The NASA Activity Monitor is most likely to penetrate the specialty applications market area. One promising application is the tunnel locator for prison use (and for which the NASA Activity Monitor was originally developed). In this application, the intruder (or escapee) is moving slowly enough that the monitor can effectively ascertain his exact location. The ability to pinpoint the exact location of a tunnel increases the effectiveness of the correctional facility and saves the money and manpower currently used to uncover tunneling activity.

*Predicast Forecast 1981, Issue No. 82, second quarter, Cleveland, Ohio (January 23, 1981).

To approximate a market for the NASA Activity Monitor in this application, officials at 10 correctional facilities in 5 states were asked to evaluate the monitor. All officials believed that institutions with maximum security facilities would benefit most from a tunnel locating device. The majority of officials, however, did not regard tunnelling as a problem at their facilities where other electronic equipment (e.g., microwaves, fence and seismic sensors) was being used to detect above-ground activity. Three officials believed that the facility or facilities in their states (California, Colorado, and Washington) could benefit from the NASA Activity Monitor.

Using Law Enforcement Assistance Administration figures, there are approximately 172 maximum security prisons in the United States. Assuming that the SRI survey of prison officials represents a valid sampling and accurately reflects industry demand, approximately 52 (30%) maximum security prisons would be interested in installing the monitor. The average perimeter size of maximum security institutions is 1,060 ft, or 2.2 seismic security systems per prison. This represents a market of 114 units--not a large enough market to justify investment by a new company. The ability of the NASA Activity Monitor to compete in other markets is variable and depends mainly on user needs and the sales skills of marketing representatives.

The most common application of the NASA Activity Monitor technology will probably be seen in companies incorporating various aspects of the system into their own security systems. One company contacted expressed interest in adapting the scanning/gate electronics to create small zones, with from 1 to 5 sensors, each with its own gate. Activity could then be traced to an area ranging in length from 23 ft to 115 ft. This degree of accuracy would satisfy user needs and increase the area that can be monitored by one console, thereby increasing the chance of acceptance by manufacturers. Scanner electronics could be offered as an optional attachment, lowering the risk to the manufacturer and testing consumer reaction. If demand should prove to be great enough, the scanner electronics could then be incorporated into a basic monitoring unit.

The demand for seismic security equipment is expected to increase steadily, but not beyond the production capabilities of the four current manufacturers. The demand for scanner electronics, the NASA Activity Monitor's unique technology, is small, and the cost of the electronics will limit market acceptance in the fastest growing section of the security system market--home protection. If the NASA Activity Monitor technology is to be used by the commercial sector, it will have to be marketed by established dealers offering scanner electronics as optional equipment on their current systems. Sparten and GTE could use scanner electronics as a relatively inexpensive central monitoring station for their current units. IDS and Geotronics could expand their current zone coverage with scanner electronics while providing more detailed coverage of the perimeter.

Direct adaptation of the NASA Activity Monitor technology will be limited to applications similar to those described for correctional facilities. In the general market, however, the precision coverage offered by the monitor is neither necessary nor in demand.

Appendix A

**NASA CASE NO. ARC-11317:
INTRUSION DETECTION METHOD AND APPARATUS**

By

Robert Lee

DescriptionIntrusion Detection Method and ApparatusOrigin of the Invention

5 The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for Governmental purposes without the payment of any royalties thereon or therefore.

Technical Field

10 The present invention relates in general to intrusion detection systems and more particularly to an improved system utilizing an array of seismic vibrational detectors which can be scanned sequentially for intrusion detection and location of the intruder.

Background Art

15 Heretofore, perimeter intrusion detection systems have employed an array of seismic vibration sensors buried in the ground for detecting intruders. The output signals from the seismic sensors have been summed into a receiver and analyzed in various ways to produce an alarm indicative of an intrusion in the region being monitored. Examples of such systems can be found in the following
20 U.S. Patents:

3,109,165 issued 29 October 1963;
3,913,085 issued 14 October 1975; and
4,107,660 issued 15 August 1978.

25 While such systems are suitable for indicating an intrusion into a monitored perimeter they are not suited for indicating the location of the intrusion.

It is also known from the prior art of intrusion detection systems employing sonic sensors (microphones) to dispose microphones in a number of remote areas to be monitored. Means were provided
30 for selectively listening to sounds made in any one or more of the remote areas in one mode and to the sum of the sounds picked up

by all the microphones simultaneously in a second mode. An example of such a system is disclosed in U.S. Patent 3,974,489 issued 10 August 1976. While this system is suitable for monitoring a relatively few number of remote areas it is not generally suited for monitoring a
5 perimeter having a relatively large number of sensors such as 20 or more because the operator had to manually select each individual remote location when operating in the selective mode.

[Statement of Invention]
Disclosure of Invention

10 In the present invention, an array of seismic vibrational sensors are spaced at intervals along a perimeter to be monitored. The outputs of the individual sensors are fed back to a central monitoring station. At the monitoring station, three different modes of operation are provided. In a first mode
15 of operation, all of the outputs from the various sensors are summed into the receiver to sound an alarm when an intrusion is made anywhere into the monitored perimeter. In a second mode of operation, the outputs of the various sensors are multiplexed into the receiver for scanning the individual outputs of the sensors.
20 When a sensor output exceeds a certain threshold value the multiplexing action stops on that sensor thereby giving an indication of the location of the intrusion. In a third mode, the operator can manually scan up and down the sensors in the immediate vicinity of the sensor on which the automatic scan mode stopped to derive
25 a more precise location of the intrusion.

Brief Description of the Drawings

Fig. 1 is a longitudinal sectional view along an array of sensors employed in the system of the present invention,

Fig. 2 is a side elevational view of an alternative seismic
30 sensor employed in the array of the present invention,

Fig. 3 is a schematic block diagram of an intrusion monitoring and detection system incorporating features of the present invention,

Fig. 4 is a schematic circuit diagram for the receiver portion of the system of the present invention, and delineated by line 4-4 of Fig. 3,

5 Fig. 5 is a schematic diagram, partly in block diagram form, of the intrusion detection and monitoring system of the present invention, and

Fig. 6 is a schematic circuit diagram, partly in block diagram form of the toggle portion of the circuit of Fig. 5 delineated by line 6-6.

10 Detailed Description of the Invention

Referring now to Fig. 1 there is shown a linear array of seismic sensors 11 as employed for monitoring intrusion into a perimeter. In a typical example, the sensors 11 are of the moving coil geophone type such as model L-21A available from Mark Products, Inc., of Houston, Texas. Each of the sensors 11 has a pair of
15 leads over which the signals generated by the sensor are transmitted to a central intrusion monitoring station 12. Typically, the leads to each of the sensors 11 are contained in a buried cable 13. In a typical example, the sensors 11 are spaced at 23 foot
20 intervals to monitor a perimeter as of 460 feet long by 23 feet wide with 20 sensors. The sensors 11 pick up the seismic vibrations produced by surface movement such as footsteps and the like. In addition, they will detect underground movements such as tunnelling.

Referring now to Fig. 2 there is shown an alternative seismic transducer 14. In this transducer a seismic vibration waveguide 15 such as a stainless steel rod as of 1/2 inch to 3/4 inch diameter and with a length of 10-20 feet is driven into the soil with the top end of the rod 6-12 inches below ground level. The seismic sensor 11 is then mechanically coupled, as by a threaded
25 coupling into the top end of the waveguide rod 15. The advantage of the alternative seismic transducer 14 is that the waveguide rod 15 facilitates transmission of tunnelling noises at substantial depths into the seismic sensor 11.

Referring now to Fig. 3, there is shown the basic features of
35 the intrusion detection and monitoring system of the present invention. Each sensor 11 is connected by a pair of wires 16 into an array

of gates 17. There is a gate for each one of the respective sensors 11. When the intrusion monitoring and detecting system 12 is operating in the summing mode (ALL) the outputs of all of the sensors 11 are summed in a receiver 18. All of the gates 17 are simultaneously enabled. The summed seismic signals are then amplified and detected in the receiver 18 and the output of receiver 18 consisting of signals in the band pass of 10 to 500 hertz are fed to the input of an audio detector 19 wherein they are compared against a certain threshold signal level (trigger). If the received signal exceeds a certain threshold level an output is fed to an audio oscillator 21 to cause the audio oscillator to generate an audible tone or alarm which is thence fed to a speaker 22 to sound an alarm to the operator.

A second output of the receiver 18 is fed to an automatic gain control detector 23 to produce an output which is fed to a switch 24. In one position of the switch 24, the output of the automatic gain control detector is fed to an automatic gain control circuit 25 to generate a DC output for controlling the gain of the receiver 18 such that the gain of the receiver is controlled to a level slightly less sensitive than the background seismic noise level along the perimeter being monitored. In this manner, only seismic signals exceeding the background level are detected to produce alarms. In a second setting of the switch 24, the automatic gain control circuit is disabled and a manual gain control circuit 26 is enabled which allows the operator to adjust the gain of the receiver 18 to a desired level.

In a second operating mode of the intrusion detection and monitoring circuit 12, the ALL or SCAN switch 20 is switched to the SCAN position which enables a scanner 27 to multiplex the output of the individual sensors 11 sequentially into the input of the receiver 18. The scanner includes an up-down counter run by a clock such that the various gates 17 are sequentially opened for repetitively scanning through the individual sensors 11. Again, as in the ALL mode, if the output signal of any one of the sensors 11 exceeds a certain predetermined threshold value, the output of the audio detector 19 initiates an audible alarm via the speaker 22.

In addition, a second output of the audio detector 19 produces a stop pulse which is fed to the scanner 27 to stop the scanning action at the sensor having the output exceeding the predetermined threshold value. A second output of the scanner is fed to an
5 array of light emitting diode indicators 28 there being one indicator for each of the respective seismic sensors 11. Thus, as the scanner multiplexes the output of the various sensors 11 into the receiver 18, the respective indicator lights 28 will sequentially light showing to the operator the particular sensor being interrogated
10 at any given time. When the output of any one of the sensors exceeds the predetermined threshold, as previously mentioned, the scanner stops scanning and the operator then by operation of an up-down switch 29 causes the scanner to advance or back up for monitoring the individual sensors in the vicinity of the
15 sensor which first indicated a signal exceeding the predetermined threshold.

Thus, the third mode of operation is the manual up-down scan which causes the scanner 27 to advance or back up by one sensor for each actuation of the manual up-down switch 29. The operator,
20 by monitoring the relative signal levels at the sensors in the vicinity of the sensor first to pick up the vibrations can more precisely determine the location of the intrusion, if any. To restart the automatic scanning action, the operator presses a START switch 30 which reenables the automatic action of the scanner 27.

Referring now to Fig. 4 there is shown the circuit for that
25 portion of the schematic diagram of Fig. 3 delineated by line 4-4. The output of the gates 17 is received on receiver input terminal 31 and thence fed through a band pass filter amplifier consisting of R-C elements and an operational amplifier 32. The R-C
30 elements are selected so that the band pass of the circuit is from 10-500 hertz. In a typical example, the operational amplifier 32 is one quarter of a MLM324P quad operational amplifier commercially available from Motorola. The output of the operational amplifier 32 is thence fed through an automatic gain control attenuator 33
35 whose overall gain is varied by a DC voltage received at its gain control input 34. In a typical example, the gain control attenuator 33 comprises a MC3340P electronic attenuator commercially available from Motorola.

The output of the automatic gain control attenuator 33 is thence fed through a pair of series connected low pass operational amplifiers 35 and 36 such as one half of the MLM324P quad operational amplifier. One output of the low pass operational amplifier 36 is
5 fed to one input of an amplifier detector 37, such as a 2N4250 commercially available from Fairchild, which detects the background noise voltages and feeds them to the input of an integrator consisting of R-C elements 38. The output of the integrator 38 is fed to the AUTO terminal of switch 24. When switch 24 is in the
10 AUTO position, the integrated background noise voltages are fed to the input of a voltage follower operational amplifier 41, such as a one quarter of the MLM324P quad operational amplifier, which amplifies the noise voltages to produce an output DC voltage fed to the DC voltage control terminal 34 of the automatic gain
15 control attenuator 33. When the switch 24 is set to the second or MANUAL position, a manually adjustable DC feedback voltage is developed from a potentiometer 42 and fed to the voltage follower 41 and thence fed back to the gain control terminal 34 of the gain control attenuator 33.

20 A second output of the low pass operational amplifier 36 is voltage divided via a potentiometer 43 and thence fed to the input of an audio detector 44, such as one quarter of a CD4011AE positive NAND gate from RCA. The output of the audio detector 44 is rectified via rectifier 45 and integrated via capacitor 46 and resistor 47 to
25 derive an input to a stop pulse amplifier 48. The output of the stop pulse amplifier 48 is fed to the scanner 27 to stop the scanner on the sensor having the signal level above the predetermined threshold level determined by the setting of the trigger potentiometer 45.

30 A second output of the integrator is fed to the input of a pulse audio oscillator 49, such as one half of the quad CD4011AE positive NAND gate. The output of the pulse audio oscillator 49 is fed to the input of a driver amplifier 51. In a typical example, the driver amplifier comprises one quarter of the MLM324P operational amplifier. The output of the driver amplifier 51 is fed to the
35 input of a power amplifier 52. The output of the power amplifier 52 is fed to the speaker 22, to provide an audible alarm when the

output of the receiver 18 exceeds a certain threshold as determined by the setting of the trigger potentiometer 43 and gain control. A suitable power supply provides +10 volts DC on terminals V_1 , V_2 , and V_3 .

5 Referring now to Figs. 5 and 6, the scanner 27 and gate circuits 17 are shown in greater detail, respectively. More particularly, the output lines 16 from each of the respective geophones 11 in the array are coupled to the input of an array of analog gates 17 such as CD4066AE bilateral switches commercially available
10 from RCA. The output of the gates 17 is coupled onto a bus 53 connected to the input of the receiver 18. The respective gates 17 are driven from the output of an array of buffer pulse amplifiers 54. An array of light emitting diodes 28 as indicators are provided, one for each of the respective seismic sensors. The
15 positive terminal of each of the light emitting diodes 28 is connected to the output of the buffer pulse amplifier 54 and thus the input to the respective gate 17. The negative terminals of the diodes 28 are connected via the ALL or SCAN switch 20 to ground via load resistor 55 when the switch 20 is in the SCAN position.

20 The array of buffer pulse amplifiers 54 is fed from the output of an array of tri-state buffer amplifiers 56 such as a CD4502BE strobed hex buffer from RCA. When the ALL or SCAN switch 20 is in the SCAN position one input line to the respective tri-state buffer amplifiers 56 is grounded and the other line is driven from
25 the output of a respective one of an array of multiplexer gates 57 such as CD4066AE bilateral switches. The respective multiplexer gates are driven from the output of a decoder such as a model CD4028AE BCD-to-decimal decoder 58 commercially available from RCA. In the SCAN mode, only one of the respective gates 57 will
30 be energized or open so as to enable its respective tri-state buffer which drives the respective buffer pulse amplifier 54 to turn on the respective gate 17 for outputting onto the gate bus 53 the output of the respective seismic sensor 11.

In the ALL mode the ALL or SCAN switch 20 is switched to the
35 ALL position, this disables all of the light emitting diodes 28 and enables all of the tri-state buffer amplifiers 56 by placing a positive 10 volts on one of the input terminals thereto thereby

opening all of the gates 17 and serving to sum on the gate bus 53 all of the outputs of the respective seismic sensors 11. A light emitting diode 59 is also connected by the ALL or SCAN switch 20 to a source of positive 10 volts at V_3 , thus energizing an ALL indicator light 59 indicating that the scanner is in the ALL mode.

The decoder 58 decodes a BCD count derived from an up-down counter 61 such as a CD4029AE up-down counter from RCA. The gates 57 are AND gates and are arranged in two sets of ten each. The output of the decoder 58 is fed in parallel to each set of ten AND gates. A second output which enables each respective set of gates 57 is derived from the output of a flip flop 62 which receives an input from the output of the counter 61 when the count has reached a count of ten so that on every other count of ten the same set of ten gates 57 is enabled. The counter 61 is advanced from a free running clock oscillator 63, such as a CD4060AE binary counter/divider and oscillator available from RCA, having its output amplified by a pulse amplifier 64 and thence fed to the input of the up-down counter 61.

Thus, in the SCAN mode, the free running clock 63 continues to feed a train of pulses into the counter 61 which then outputs a BCD count to the decoder 58 which decodes the count to sequentially energize ten output lines 65 feeding in parallel the two sets of ten AND gates 57 for sequentially opening respective ones of the gates 57. When the receiver 18 receives a signal exceeding its trigger threshold value it initiates a stop pulse which is fed via a pulse amplifier 66 into the input of a set-reset flip flop 67 which outputs a signal to the clock oscillator 63 for turning off the clock 63. This stops the scanning mode at the seismic sensor 11 having an output signal exceeding the predetermined threshold value.

The operator can then manually scan up or down relative to the seismic sensor on which the automatic scan has stopped. The operator scans up and down manually by operating the switch 29 which selectively energizes either an up or down input terminal of a toggle electronic circuit 69. One output of the toggle 69 is an up down control signal 71 for causing the counter 61 to count either up or down in accordance with the selection of the switch 29. A second output of

the toggle electronics 69 is a single pulse which is fed to the input of the pulse amplifier and thence to the counter for causing the counter 61 to count one count either up or down in accordance with the sense of the count signal fed via output 71 to the
5 counter 61. After the operator has listened to the seismic sensors on either side of the sensor on which the scan stopped or is finished with the manual scan, the operator presses the START switch 30 which resets the set-reset flip flop 67 to produce an output which starts the free running clock 63 and the automatic scan mode is
10 thus restarted.

Referring now to Fig. 6 there is shown the toggle electronic circuit 69. More particularly, depending upon which terminal the switch 29 is manually set to, either up or down, a respective one shot 73 or 74 is energized to produce a respective output pulse of a
15 duration of approximately 1/2 second. The output of the respective one shot 73 and 74 is fed to a latching generator 75 which latches to +10 volts as long as one of the one shots 73 is triggered but reverses its latch output to ground when the other one shot is triggered. The latch output is coupled through an amplifier 76
20 to the up-down input of the counter 61. The output of the respective one shot 73 is also fed through an amplifier 77 to provide a single clock pulse to advance the counter when either one shot 73 or 74 is triggered.

The advantage of the intrusion monitoring and detection
25 apparatus of the present invention is that it provides means for automatically sequencing through the respective sensors in the array and will automatically stop on a sensor having an output exceeding a certain threshold value. The operator can then manually interrogate sensors on either side of the sensor on which
30 the scan has stopped to more precisely pinpoint the location of the seismic vibrations. In addition, the intrusion monitoring apparatus provides a second mode of operation wherein all of the seismic sensors can be monitored simultaneously.

Claims

1. In a method of intrusion detection, the steps of:
multiplexing into a receiver at a central location individual
electrical signals developed by vibration sensed by individual
ones of a plurality of seismic sensors in an array disposed
5 in a monitored region within which intrusion by surface
movement or tunnelling is to be detected to obtain a scan
of the seismic sensors in the array; and
automatically stopping the multiplexing scan on a first
individual sensor having a received vibration signal
10 exceeding a predetermined threshold value to indicate
the location of an intrusion.
2. The method of claim 1 including the step of sequentially
selecting the received signal developed on second and third
seismic sensors in the vicinity of said first sensor to
15 more precisely determine the location of the intrusion.
3. The method of claim 1 including, automatically adjusting
the gain of the receiver to compensate for changing
background vibrational noise so as to maintain optimum
sensitivity of the receiver near the threshold of the background
20 noise level.
4. The method of claim 1 including the step of, disabling the
multiplexing of the received signals and enabling
simultaneous receiving of the plurality of individual
electrical vibration signals by the receiver; and
25 monitoring the summation of all of the simultaneously
received signals to detect intrusion somewhere within
the monitored region.

5. In an intrusion detection apparatus;
a plurality of individual seismic sensor means for disposition in an array in a monitor region within which intrusion by surface movement or tunnelling is to be detected for
5 developing individual sensed vibration signals picked up by the individual seismic sensor means;
receiver means for disposition at a central location for receiving and detecting the signals developed by said seismic sensor means;
10 multiplexing means for multiplexing the individual sensed vibration signals into said receiver means; and
means for automatically stopping the multiplexing scan on a first individual sensor means having a developed vibrational signal exceeding a predetermined threshold
15 value to indicate the location of an intrusion.
6. The apparatus of claim 5 including means for sequentially selecting the received signal developed on second and third seismic sensors in the vicinity of said first sensor means to more precisely determine the location of the
20 intrusion.
7. The apparatus of claim 5 including automatic gain control means for adjusting the gain of said receiver means to compensate for changing background vibrational noise so as to maintain optimum sensitivity of said receiver means near the threshold
25 of the background noise level.
8. The apparatus of claim 5 including means for disabling said multiplexing means and enabling simultaneous receiving by said detector means of the plurality of individual vibration signals sensed by said sensor means; and
30 means for monitoring the summation of all of the simultaneously received signals to detect intrusion somewhere within the monitored region.

Intrusion Detection Method and Apparatus

Abstract

An intrusion monitoring system includes an array of seismic sensors, such as geophones, arranged along a perimeter to be monitored for unauthorized intrusion as by surface movement or tunnelling. Two wires lead from each sensor to a central monitoring station. The central monitoring station has three modes of operation. In a first mode of operation, the output of all of the seismic sensors is summed into a receiver for amplification and detection. When the amplitude of the summed signals exceeds a certain predetermined threshold value an alarm is sounded. In a second mode of operation, the individual output signals from the sensors are multiplexed into the receiver for sequentially interrogating each of the sensors. Again, if the output from any one of the sensors exceeds a certain predetermined threshold value, a stop pulse is generated which stops the multiplexer at that sensor. A third operating mode permits the operator to manually scan up and down the individual sensors in the vicinity of the output sensor which stopped the action of the multiplexer. In this manner a more precise location of the intrusion is obtained. An automatic gain control is provided for the receiver allowing the sensitivity of the receiver to be automatically adjusted for optimum sensitivity with changing background noise level.

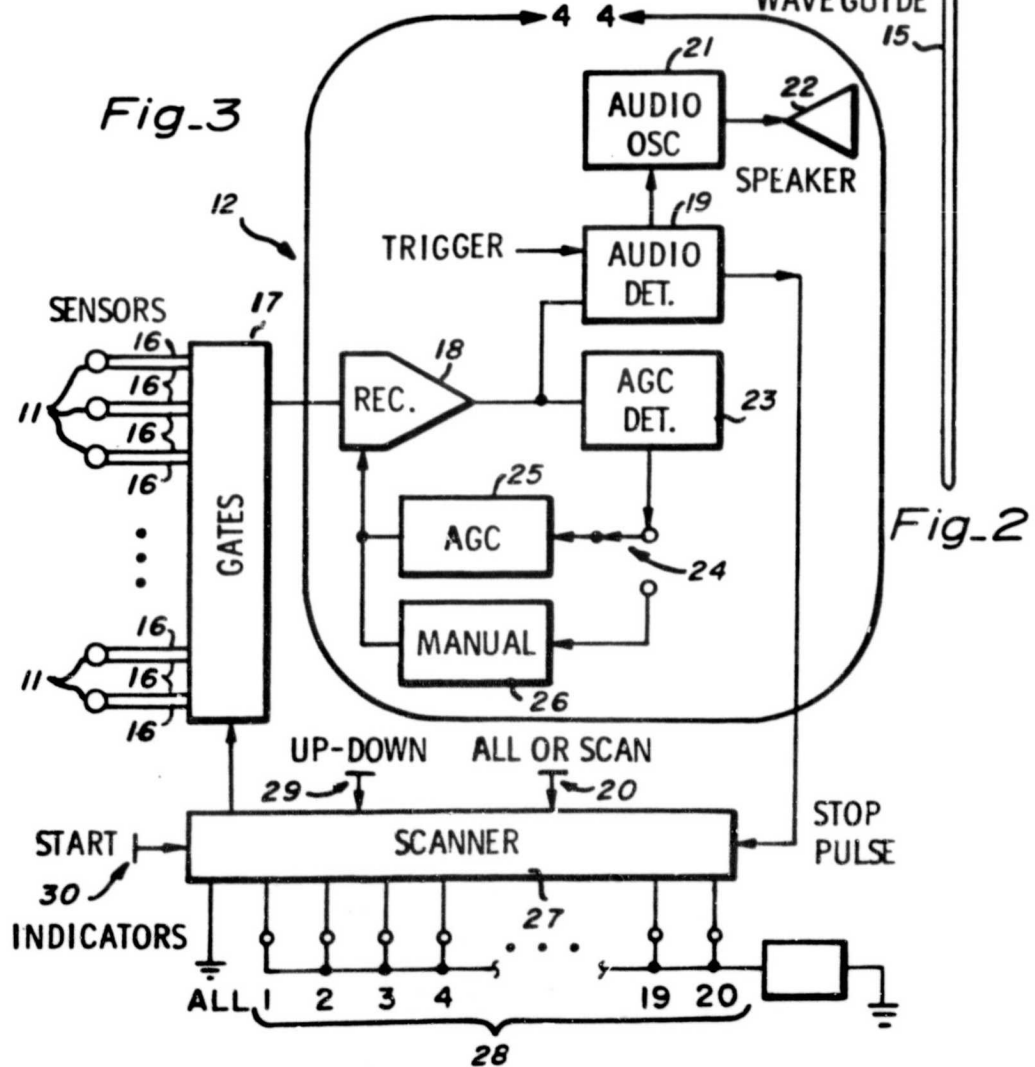
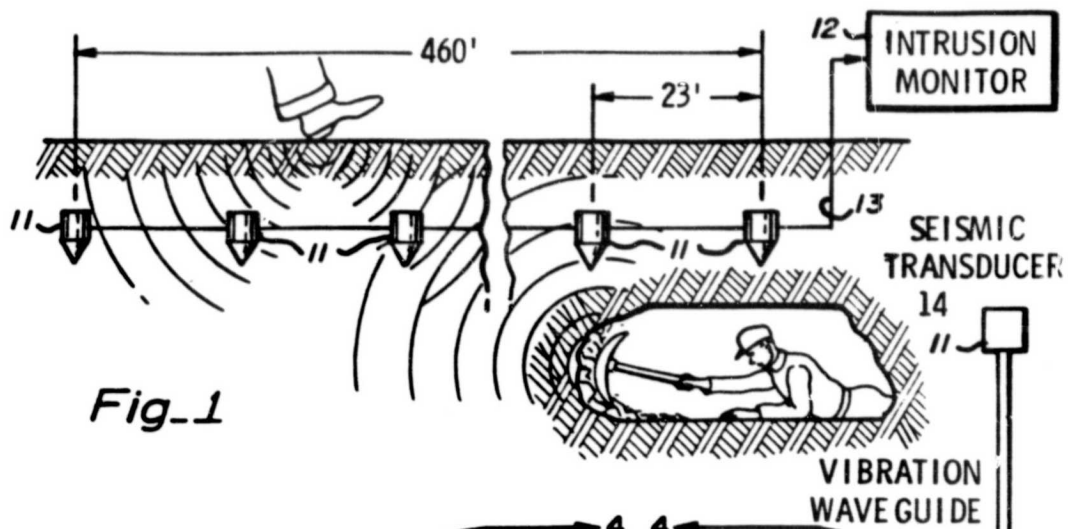


Fig. 2

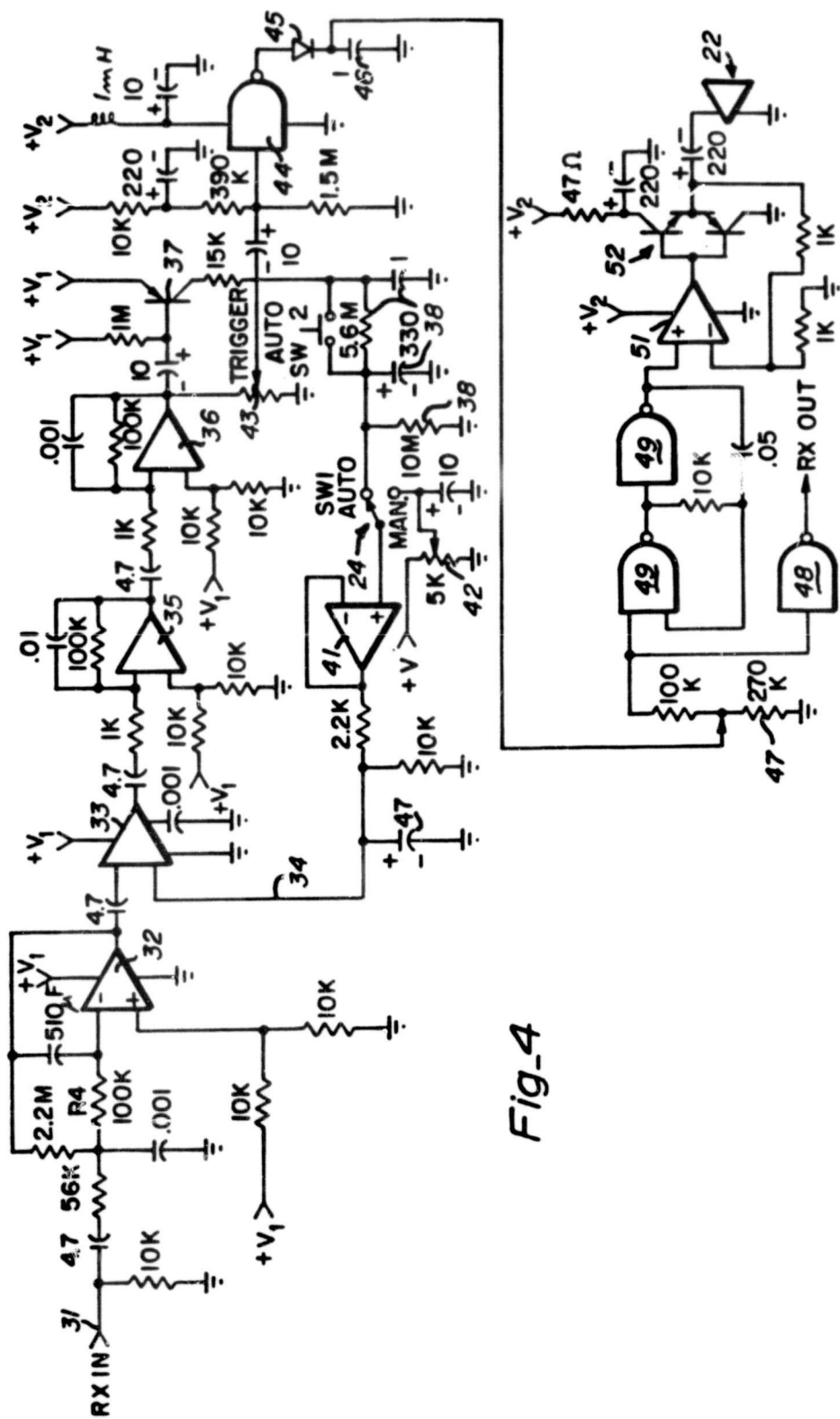


Fig-4

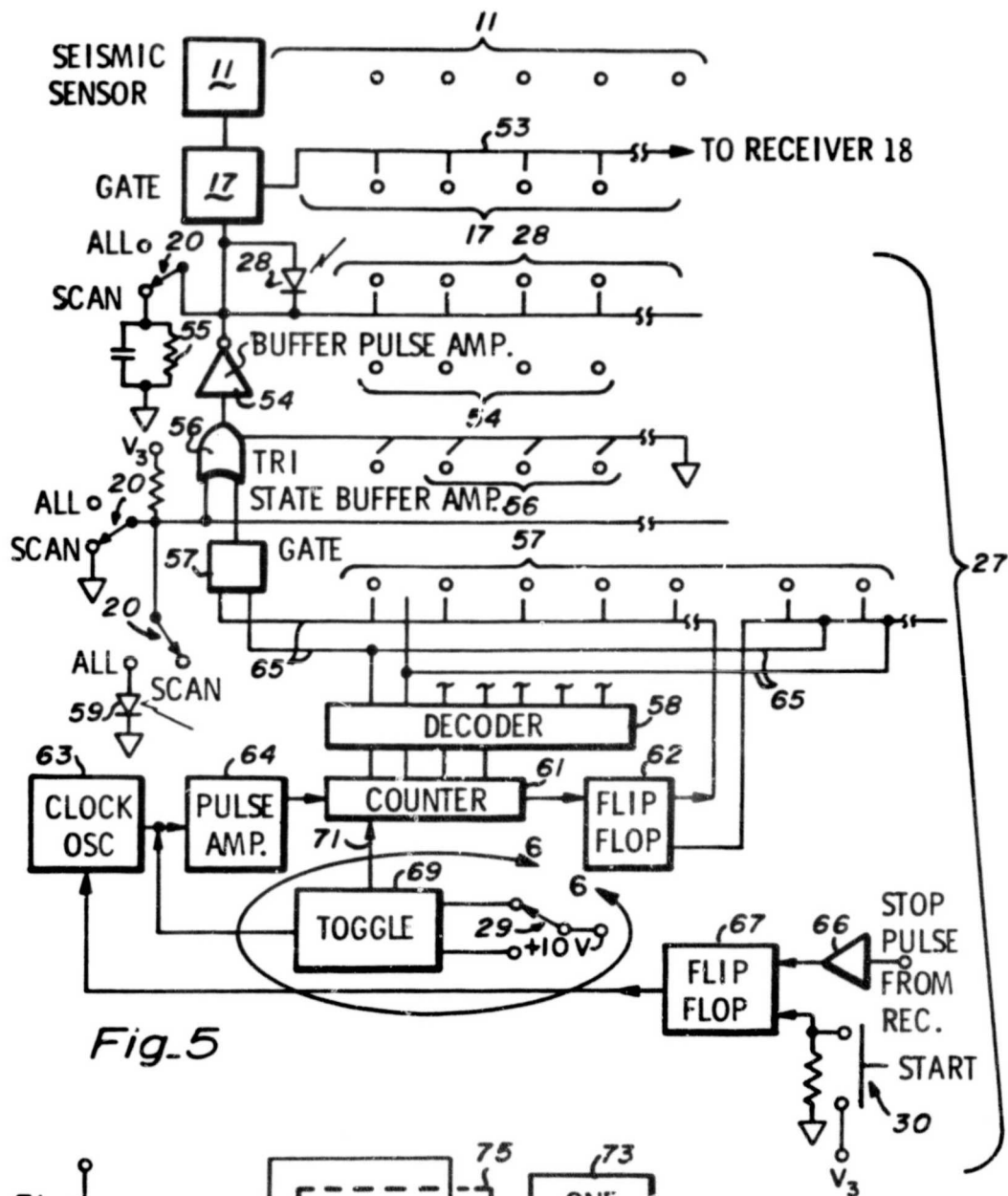


Fig. 5

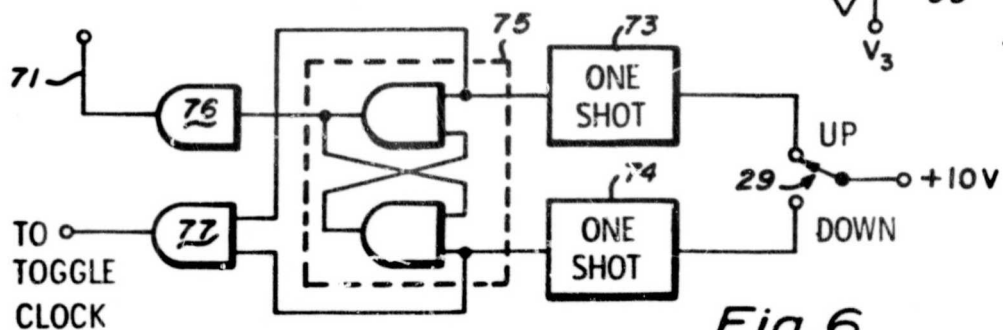


Fig. 6